MEASUREMENT OF HO_2 AND OTHER TRACE GASES IN THE STRATOSPHERE USING A HIGH RESOLUTION FAR-INFRARED SPECTROMETER AT 28 KM

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1. Personnel Working on this Grant During this Reporting Period

Dr. Wesley A. Traub (Principal Investigator)

Dr. Kelly V. Chance (Principal Investigator)

Dr. Stephen C. Wofsy (Co-Investigator)

Dr. David G. Johnson (Physicist)

Mr. Amit Ghosh (Programmer Analyst)

Both Dr. Johnson and Mr. Ghosh joined this program during the current reporting period, and both are working full time on the grant. Dr. Johnson recently earned his Ph.D. in physics from Princeton University, doing a precision measurement of the cosmic background radiation from a balloon platform. Mr.Ghosh earned an M.S. in astrophysics from Moscow State University and an M.S. in physics from the University of New Hampshire.

2. Status Summary

This status report reviews the major events and results to date of our ongoing program of measuring stratospheric composition by the technique of far-infrared Fourier-transform spectroscopy from a balloon-borne platform. The report covers an 18 month period, of which the first 9 months has already been discussed in some detail in the History section of our September 1987 grant renewal request. The highlights of this period were the two balloon flight campaigns which we carried out at Palestine, Texas, both of which produced large amounts of scientifically useful data. Since these were the first two flights of our newly-built second-generation far-infrared spectrometer (FIRS-2), we are of course exceptionally pleased with the success of these flights, and the large amounts of scientifically productive data which have been generated.

3. Instrumentation

During approximately the first eight months of this reporting period, we completed and fully tested the FIRS-2 instrument, including the Fourier transform spectrometer, the telescope and single-axis platform stabilized pointing system, and the flight electronics. For the first flight, our ground support electronics (GSE) was very limited in the sense that we had no independent data recording capability, and had to rely entirely on the National Scientific Balloon Facility (NSBF) for data capture. Fortunately, just prior to the second flight, we were able to enhance our GSE by the addition of a new 386-based computer and optical disk storage system, which has now been fully integrated with the instrument. This work, which was done in the remarkably short time of a few weeks, was completely successful, and has for the first time given us the ability to take data, record it on either a hard disk or on the optical disk, send it via an Ethernet line to either our own Microvax (when at the SAO) or the NSBF Microvax (when in Palestine), trans-

form the data on the spot, and then display any desired section of spectrum or interferogram for quick-look analysis. This rapid turn-around capability has completely changed the way we work, and has been extremely helpful in giving us the ability to diagnose the quality of data within a few minutes of the time it is obtained.

For the first flight, the completed and tested instrument was shipped to the Jet Propulsion Laboratory (JPL) and integrated mechanically and electrically with a JPL-built balloon gondola in August 1987. Following this integration, which went very smoothly, the instrument and gondola were shipped together to Palestine, Texas.

4. Field Measurements

The first balloon flight of the FIRS-2 instrument took place on October 4, 1987. The launch was at 10:30 am, local time. Spectra were taken during ascent, from 11:35 am to 12:49 pm, followed by float spectra from 12:56 pm until 8:32 pm. The flight was terminated early (unfortunately, before the sunset transition) because the float winds took the package to the edge of the termination zone surrounding the Houston area. However, 9 hours of useful stratospheric spectra were obtained, and are currently being analyzed. Figure 1 shows four spectral segments from a single 3-minute scan obtained during this flight, at an elevation angle of -2.32 degrees. (As is explained later in this report, we are still working on the software to properly do the phase correction of these spectra.) The OH lines in these spectra stand out beautifully both from the interference of nearby water (and other) lines, as well as from the background noise.

Of the four independent detectors which we have in the dewar, measuring in parallel four separate spectral bands, only three were functioning properly during this flight, since after the balloon reached stratospheric altitudes, it became apparent that preamplifier number 2 had become very noisy; later analysis suggested that this unexpected condition resulted from the dramatically reduced background load seen by the detector in flight, coupled with a bias setting which had been optimized for a high (lab) background, which is our normal practice, but which in the case of this particular detector seems not to have worked. The instrument was recovered intact, and returned to our lab at the SAO. There we discovered that the dewar had suffered extensive internal damage during the truck ride immediately after recovery; this damage required re-welding of the helium vessel support neck, and a second round of optical realignment. At this time we also found that the polished metal support plate for the Mylar beamsplitter was sufficiently warped that we decided to quickly replace it with a glass ring. We also solved a few electronic problems in the flight hardware at this time. The instrument was shipped back to Palestine in April 1988.

The second flight of the FIRS-2 instrument was our most successful balloon flight to date. We flew again on the same JPL gondola. The launch was on May 12, 1988 at 9:42 am. We obtained spectra on ascent from 11:04 am until 12:39 pm. Limb-scanning sequences of spectra were taken at float altitude from 12:44 pm until 5:30 am, May 13, when the liquid helium in the detector dewar was exhausted. This period repre-

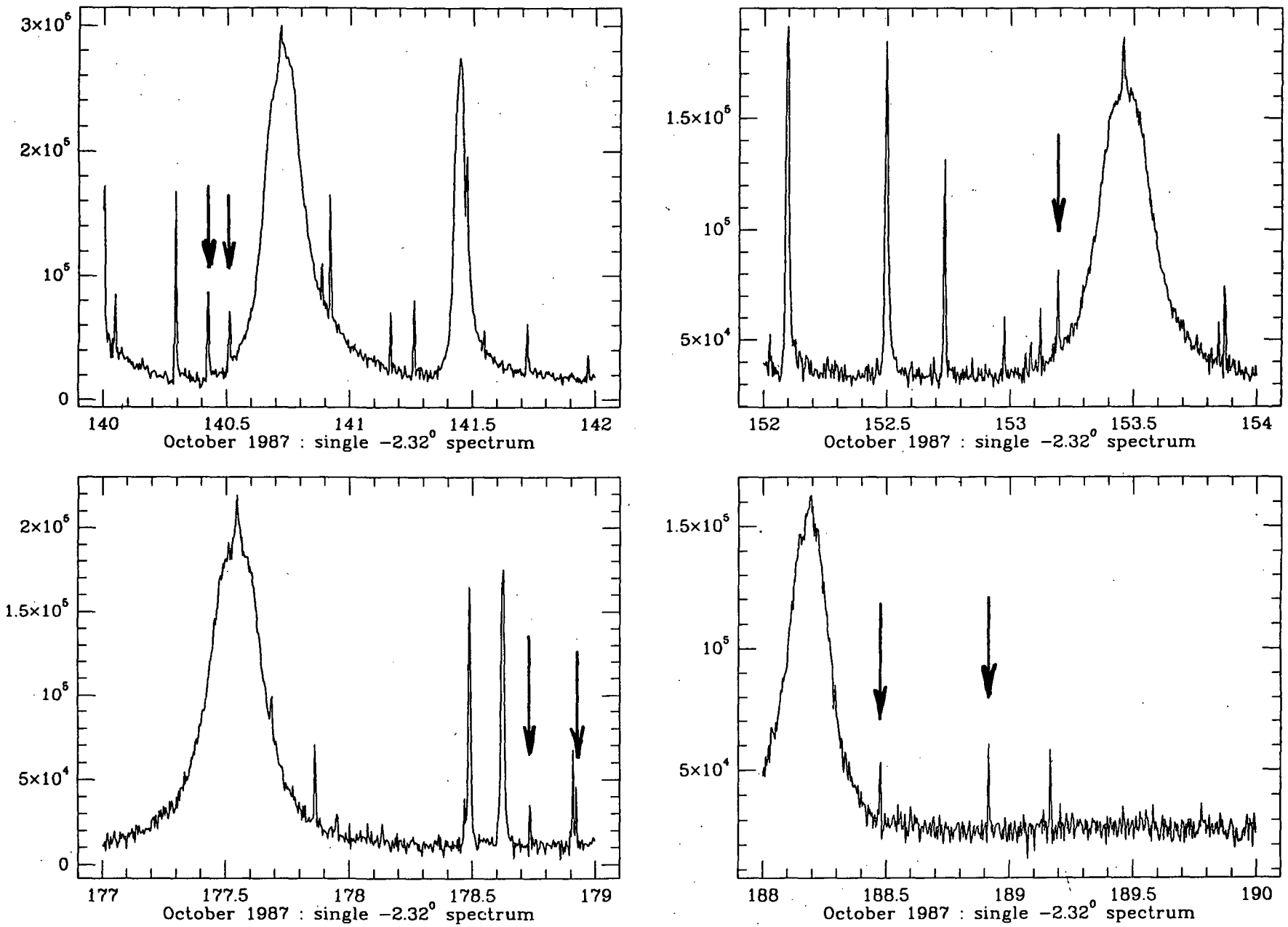

Figure 1. Four spectral segments from the FIRS-2 October 1987 flight, showing OH emission lines standing out clearly from both their neighbors as well as the noise.

sents most of the diurnal cycle, including the full sunset transition. The complete FIRS-2 system performed flawlessly for this entire time. The flight was terminated shortly after noon on May 13, and was recovered with no damage to the gondola or instruments. We obtained 17 hours of continuous and virtually perfect stratospheric data during this flight, surpassing the 13 hours of float data which we gathered during our last flight with the FIRS-1 instrument during the BIC-2 campaign in June 1983.

Figure 2 shows a sum of 8 spectra taken with one of the far infrared detectors; this detector receives the short-wavelength output of a metal-mesh diplexer and is useful from about 110 to 190 cm-1. The spectrum shown here is a sum of spectra taken at an elevation angle of -2.32 degrees, corresponding to a 34 km tangent height. The general quality of the spectra is excellent, as seen from the signal to noise and the clean separation of lines. Our phase correction algorithm for these high resolution spectra has not yet been completed (poor phase correction of the spectra can most easily be seen from 134 to 146 cm-1), but we expect to have have it completed shortly.

Figure 3 shows some detailed sections of the spectrum in Figure 2, and a comparison with spectra taken with the original FIRS instrument during the BIC-2 campaign under similar pointing conditions and with roughly the same integration time (24 minutes). The figure contains emission lines from OH, H2O, HDO, vibrationally excited H2O, O3, atomic oxygen, HCl, and HF. The benefit of the eight times increase in resolution of FIRS-2 is obvious in the separation of atmospheric lines.

5. Data Analysis

We have substantially improved and extended our far infrared spectral database, in preparation for the analysis of spectra from the FIRS-2 instrument. The database now includes spectral parameters from the 1986 AFGL HITRAN line listing, the 1984 Jet Propulsion Laboratory Submillimeter line listing, high resolution tunable far infrared measurements performed at the National Bureau of Standards, as well as from spectroscopic calculations we performed at SAO. Our database currently includes lines of: H2O (including isotopes and hot bands), OH, HO2, and H2O2; O3P, O2 (including isotopes), and O3 (including isotopes and hot bands); HF, HCl, HBr, and HOCl; CO, and NO2.

There has, of course, been an extensive effort put into computer programs and systems work on both our existing Microvax and our new 386-based computer. The original programs which we had for FIRS-1 have been upgraded for FIRS-2 from 2 channels to 4 channels, and each of these has gone from about 8 K samples to about 64 K samples per spectral scan. New graphics capabilities have been implemented, and many new data-handling programs have been written to process and display both our housekeeping as well as science data.

At the moment, we are temporarily being held back from fully exploiting our rich data base because of an aspect of the interferograms which has heretofor been not fully manifested. In particular, we find that when we do the Fourier transform which takes the recorded inter-

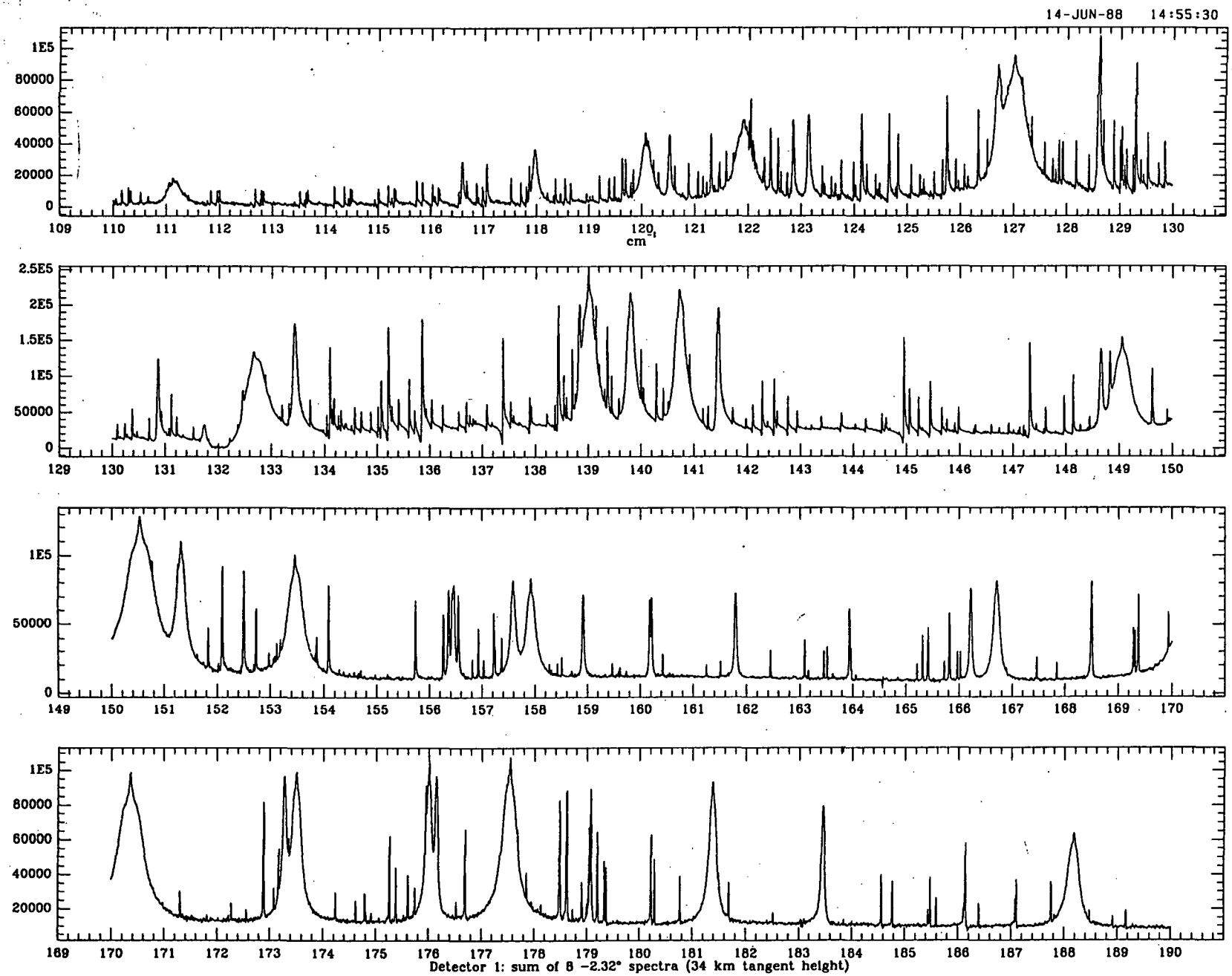

Figure 2. The raw spectrum from FIRS-2 detector 1, from 110 to 190 wavenumbers, summed over 8 individual scans. The detector and filter response have not yet been removed. Phase errors can be seen in the non-symmetric shapes of lines in the second panel.

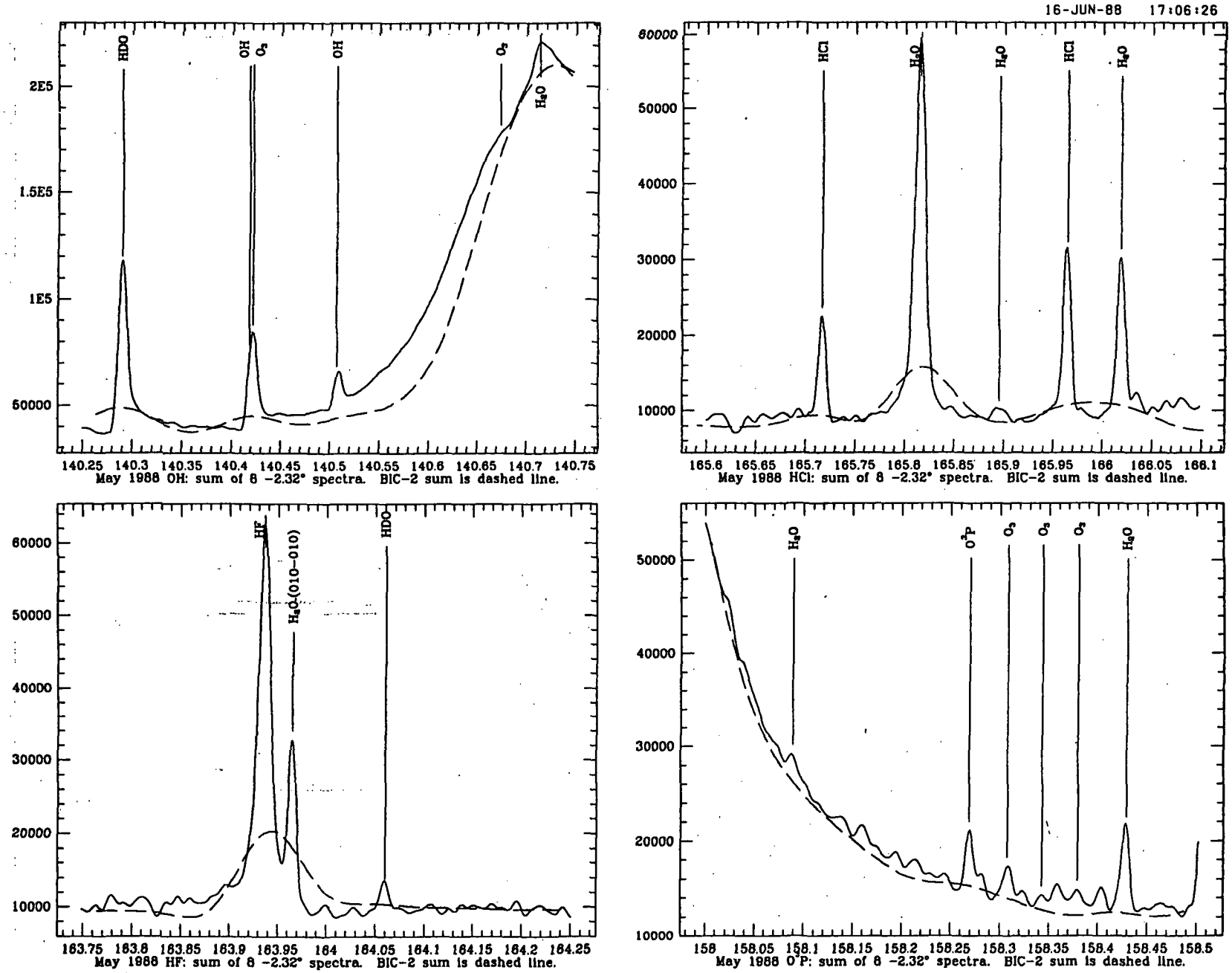

Figure 3. Four spectral segments selected from the FIRS-2 data in Figure 2, shown as a solid line. The dashed overlay line is an eyeball-scaled spectrum from our FIRS-1 measurements during the 1983 BIC-2 campaign, under roughly comparable conditions.

ferogram and turns it into a spectrum, we end up with a composite spectrum, in the sense that the low-level instrumental emission background spectrum appears with a complex phase angle which in general differs from that of the atmospheric spectrum, by an amount which varies across the spectrum, andwhich ranges in magnitude up to about 60 degrees or so. In order to properly treat the data, we are now in the midst of an extensive program designed to allow us to essentially subtract a complex background spectrum from each scan, rather than the conceptually much simpler process which we had previously employed of subtracting a real (i.e., in-phase) background. The mathematical treatment which we are pursuing is expected to be fully successful, but until we actually complete the process and test it fully, we will have to hold in abeyance our next step, which is to derive concentration profiles from the existing limb-scan data. We are currently making good progress in this direction, and expect to have the phase-correction algorithms well in hand by the end of this summer, if not sooner.

6. Publications

Design of a Single-Axis Platform for Balloon-Borne Remote Sensing, L.M. Coyle, G. Aurilio, G.U. Nystrom, J. Bortz, B.G. Nagy, K.V. Chance, and W.A. Traub, Review of Scientific Instruments 57, 2512 (1986).

Performance of a Single-Axis Platform for Balloon-Borne Remote Sensing, W.A. Traub, K.V. Chance, and L.M. Coyle, Review of Scientific Instruments 57, 2519 (1986).

Evidence for Stratospheric Hydrogen Peroxide, K. V. Chance and W. A. Traub, Journal of Geophysical Research 92, 3061 (1987).

Atomic Oxygen in the Lower Thermosphere, F.J. Lin, K.V. Chance, and W.A. Traub, Journal of Geophysical Research 92, 4325 (1987).

Ozone Measurements During the Balloon Intercomparison Campaign, D. Robbins, J. Waters, P. Zimmerman, R. Jarnot, J. Hardy, H. Pickett, S. Pollitt, W. A. Traub, K. Chance, N. Louisnard, W. Evans, and J. Kerr, to appear in Journal of Atmospheric Chemistry (1988).

Intercomparison of Measurements of Stratospheric Hydrogen Fluoride, W. G. Mankin, M. T. Coffey, K. V. Chance, W. A. Traub, B. Carli, A. Bonetti, I. G. Nolt, R. Zander, D. W. Johnson, G. Stokes, C. B. Farmer, and R. K. Seals, to appear in Journal of Atmospheric Chemistry (1988).

Intercomparison of Stratospheric Water Vapor Profiles Obtained During the Balloon Intercomparison Campaign, D. G. Murcray, A. Goldman, J. Kosters, R. Zander, W. Evans, N. Louisnard, C. Alamichel, M. Bangham, S. Pollitt, B. Carli, B. Dinelli, S. Piccioli, A. Volboni, W. A. Traub, and K. Chance, to appear in Journal of Atmospheric Chemistry (1988).

Balloon Intercomparison Campaign: Results of Remote Sensing Measurements of HCl, C. B. Farmer, B. Carli, A. Bonetti, M. Carlotti, B. M. Dinelli, H. Fast, N. Louisnard, C. Alamichel, W. Mankin, M.

Coffey, I. G. Nolt, D. G. Murcray, A. Goldman, G. Stokes, D. Johnson, W. Traub, K. Chance, R. Zander, L. Delbouille, and G. Roland, to appear in Journal of Atmospheric Chemistry (1988).